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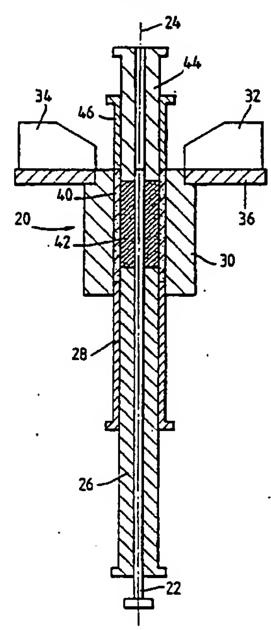
(54) Method of manufacturing a magnetic device.

(57) A method of manufacturing an electromagnetic device having regions of ferromagnetic material and permanent magnet material utilizes thermoplastic encapsulated iron powders and epoxy resin encapsulated permanent magnet powder. A motor frame and permanent magnet assembly (100) is formed in a first example, while a permanent rotor assembly (10) is formed in a second. The motor frame and permanent magnet assembly (100) has a ferromagnetic frame (116) defined by a region of encapsulated iron powder and an annular array of permanent magnets (114) defined by a region of encapsulated permanent magnet material. The permanent magnet rotor assembly (10) has a ferromagnetic core (14) defined by a region of encapsulated iron powder and a permanent magnet shell (16) defined by a region of encapsulated permanent magnet material. In the processing of both the motor frame and permanent magnet assembly (100) and the rotor assembly (10), annular inner and outer punch elements (26,28) coaxial with a central core rod (22) are supported within a heated die casing (30) for independent extension and retraction along the central axis. The inner and outer punch elements (26,28) are retracted to form cavities which are filled with the encapsulated permanent magnet and ferrous powders, respectively, for the motor frame and permanent magnet assembly (100), while the reverse exists for the manufacture of the permanent magnet rotor assembly (10). Coaxial pressing mechanisms individually and concurrently compress the powders to fuse and compact them to a predetermined axial length.

Fig. 5.



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The present invention relates to a method of manufacturing a component of a magnetic device.

The use of polymer encapsulated powders to make various magnetic circuit elements is well known in the art. For example, in U.S. Patent No. 5,004,577 polymer encapsulated iron powder is utilized in the manufacture of a motor frame. Polymer encapsulated powders have also been utilized in the manufacture of permanent magnets. As noted in this patent, the encapsulant may be a thermoplastic material, and the parts may be formed by injection of preheated powder material or by compaction of powder material in a preheated die or mold.

It would be desirable to provide a simple method for production of rotors and frames for permanent magnet type dynamoelectric devices using these encapsulated magnetic powders, which method would be suitable to high volume production conditions. It would be further desirable if such a method enabled the production of various components of permanent magnet dynamoelectric devices, with a minimum of process steps and wherein the size and location of the ferromagnetic and permanent magnet regions within the devices could be easily varied.

The present invention seeks to provide an improved method of manufacturing a component of a magnetic device.

According to an aspect of the present invention, there is provided a method of manufacturing a component of a magnetic device as specified in claim 1.

This invention can provide a unique method for simply manufacturing components for permanent magnet dynamoelectric devices, from polymer encapsulated metal powders.

This method can be suitable for high volume production purposes.

The method can allow the location and size of the permanent magnet and ferromagnetic regions of the device to be readily varied.

Preferably, the method can produce a dynamoelectric device having permanent magnetic regions which are formed integrally with ferromagnetic regions of the dynamoelectric device so as to form a unitary assembly.

A preferred embodiment is directed to a method of manufacturing components of a permanent magnet dynamoelectric device, wherein two particular embodiments are (1) a motor frame and permanent magnet assembly, and (2) a permanent magnet rotor assembly, each of which utilize both iron and permanent magnet polymer encapsulated powders. In the motor frame and permanent magnet assembly, the motor frame is ferromagnetic and defined by a region of encapsulated iron powder. One or more permanent magnets are disposed on an interior surface of the ferromagnetic motor frame and are defined by isolated regions of encapsulated permanent magnet material. In the permanent magnet rotor assembly, a ferromagnetic core is defined by a region of encapsulated iron powder. A permanent magnet shell circumscribing the ferromagnetic core is defined by a region of encapsulated permanent magnet material. The dynamoelectric components are individually manufactured by a multi-step process utilizing telescoping punches in a die. As an example, in the processing of the motor frame and permanent magnet assembly, a solid spacer, or core, rod is supported along a central axis of a heated die casing. Annular inner and outer punch elements coaxial with the core rod are supported concentrically within the die casing for independent extension and retraction along the central axis. The core rod may be a fixed element of the die casing. The inner punch element, which is supported on the core rod, forms one or more magnet cavities between the core rod and the outer punch element when retracted from the die casing. The outer punch element is supported on the inner punch element, and when retracted, forms a frame cavity between the inner punch element and the die casing. The punch elements are initially extended into the die casing to expel any foreign matter. The inner punch element is then retracted to form the permanent magnet cavities, and a dispensing mechanism fills the permanent magnet cavities with a permanent magnet powder consisting of preferably permanent magnet particles encapsulated in a thermoplastic material. The outer punch is then retracted to form the frame cavity, and a dispensing mechanism fills the cavity with a composite ferrous powder. The composite ferrous powder is predominantly iron particles which are preferably encapsulated with a thermoplastic material. The inner punch is then further retracted to axially center the ferromagnetic frame and permanent magnet cavities within the die casing. Thereafter, with the die casing at a suitable temperature, coaxial pressing mechanisms (e.g., the punches themselves) individually engage the permanent magnet and ferrous powders and concurrently compress the powders to fuse and compact the same to a uniform axial length. The inner and outer punch elements are then concurrently extended into the die casing to remove the compacted fused powders from the die casing. In the resulting structure, the compacted ferrous powder defines the motor frame and the compacted permanent magnet powder defines the magnetizable regions of the permanent magnet assembly. The processing of the permanent magnet rotor assembly is notably similar to that of the motor frame assembly described above. The method utilizes a core rod and annular inner and outer punch

elements which are similarly disposed within a heated die casing. However, in the processing of the rotor assembly, the inner punch element forms a core cavity between the core rod and the outer punch element when retracted from the die casing, while the outer punch element, when retracted, forms a magnet cavity between the inner punch element and the die casing. Accordingly, the outer punch element is retracted to form the magnet cavity to allow a dispensing mechanism to fill the magnet cavity with permanent magnet powder consisting of preferably permanent magnet particles encapsulated in a thermoplastic material. The inner punch element is then retracted to form the core cavity, and a dispensing mechanism fills the core cavity with the preferred composite ferrous powder. The core rod may be a fixed element of the die or, alternatively, may be removable for use as the rotor shaft. The inner punch is then further retracted to axially center the ferromagnetic core and permanent magnet cavities within the heated die casing. Thereafter, coaxial pressing mechanisms which individually engage the permanent magnet and ferrous powders concurrently compress the powders to fuse and compact the same to a uniform axial length. The inner and outer punch elements are then concurrently extended into the die casing to remove the compacted fused powders from the die casing. In the resulting structure, the compacted ferrous powder defines the rotor core and the compacted permanent magnet powder defines the magnetizable regions of the rotor assembly.

The present invention is also directed to apparatus suitable for implementing the steps of the method of claim 1, for example to apparatus shown in any one of Figures 2 to 7 or 9 to 15.

An embodiment of the present invention is described below, by way of illustration only, with reference to the accompanying drawings, in which:

Figure 1 is a sectioned perspective view of a permanent magnet rotor assembly manufactured according to an embodiment of this invention;

Figures 2 through 7 depict a first punch and die mechanism and a manufacturing sequence for purposes of forming the permanent magnet rotor assembly according to an embodiment of this invention;

Figure 8 is a sectioned perspective view of a motor frame and permanent magnet assembly manufactured according to an embodiment of this invention;

Figures 9 through 14 depict a second punch and die mechanism and a manufacturing sequence for purposes of forming the motor frame and permanent magnet assembly according to an embodiment of this invention; and

Figure 15 is a perspective view of the punch.

With reference to Figures 1 through 7, reference numeral 10 generally designates a permanent magnet rotor assembly comprising a central shaft 12, an inner ferromagnetic core 14, and an outer permanent magnet shell 16. The ferromagnetic core 14 is formed of a compacted ferrous powder, where the individual grains of the powder are preferably encapsulated with a suitable thermoplastic material such as a polyetherimide, polyamideimide or polyethersulfone. Other thermoplastic materials are well known in the art and will not be further discussed. The permanent magnet shell 16 is formed of compacted magnetizable powder in which the individual grains of such powder are also encapsulated. Preferably, the permanent magnet powder is encapsulated with a thermoplastic similar to that used with the iron particles, but could alternatively be encapsulated in a thermosetting resin such as an epoxy. If a thermosetting resin is used on the magnetizable powder and a thermoplastic used on the ferromagnetic powder, a separate curing step may be needed to harden the thermoset. In the course of manufacture, the thermoplastic materials fuse to form a unitary structure, the permanent magnet shell 16 being effectively bonded to the ferromagnetic core 14, and the ferromagnetic core 14 being firmly secured to the shaft 12. When a thermoset (e.g., epoxy) is used with the magnetizable powders, the encapsulant is cured separately from the thermoplastic on the iron particles (e.g., the epoxy is cured before the thermoplastic coated iron particles are introduced into the dies). Thereafter, the thermoplastic material is bonded to the epoxy during the final pressing operation. The rotor 10 may be formed with the shaft 12 in place or, alternatively, the shaft 12 may be press fitted into a central opening formed in the ferromagnetic core 14.

Following compression and fusing of the encapsulated powders, the rotor assembly 10 is placed in a magnetizing fixture (not shown) and subjected to a strong magnetic field. The field aligns magnetic regimes within the magnetizable powder according to a predetermined pattern, forming permanent magnet poles in the shell 16, as shown in Figure 1.

In the illustrated embodiment of the permanent magnet rotor assembly 10, the ferrous powder is predominantly iron, and the magnet powder is predominantly neodymium-iron-boron, marketed by General Motors Corporation under the trademark "MAGNEQUENCH". The thermoplastic material encapsulating the ferrous powder (and if desired the permanent magnet powder) is most preferably an amorphous polytherimide resin, an example of which is marketed by General Electric Corporation under the trademark "ULTEM". The preferred epoxy resin for encapsulating the permanent magnet

powder is an appropriate thermosetting resin having a suitable curing agent. One such type of materials is disclosed in U.S. patent No. 4,558,077, being polyglycidyl ethers of polyphenol alkanes characterized by high glass transition temperatures. Other suitable bonding agents could be employed for encapsulation of the ferrous and permanent magnet powders.

To encapsulate the powders, the thermoplastic material is mixed with a liquid solvent and then sprayed onto individual powdered particles. To facilitate this process, a source of heated air directs powder particles upward through a vertical tube (not shown) in which the spraying occurs. The coated particles fall outside the tube and thereafter are directed back to an inlet of the tube. After a number of passes through the tube, the particles are all coated to a desired extent. In the course of this process, the solvent evaporates and may be recovered by known methods.

The manufacturing process of the rotor assembly 10 is illustrated in Figures 2 through 7, which depict a punch and die mechanism 20 during sequential manufacturing stages. In the illustrated embodiment, the punch and die mechanism 20 includes a fixed central core rod 22 aligned along a longitudinal axis 24 of a heated die casing 30. An annular inner punch element 26 is slidably disposed about the core rod 22 while an annular outer punch element 28 slidably disposed between the inner punch element 26 and the heated die casing 30. A pair of powder dispensing mechanisms 32 and 34 are slidably disposed upon a die table 36 which is located at one end of the heated die casing 30 so as to be substantially perpendicular to the longitudinal axis 24. The powder dispensing mechanisms 32 and 34 are loaded with polymer encapsulated magnet and ferrous powder, respectively, and each are adapted to direct their respective powders into the cavities formed when the inner and outer punch elements 26 and 28 are retracted, as will be more fully explained below. Vibration of the die casing 30 or any of the other elements may be employed to enhance the powder filling steps.

As shown in Figure 2, the inner and outer punch elements 26 and 28 are initially extended to expel any foreign matter from the die casing 30. The outer punch element 28 is then retracted, as shown in Figure 3, to form a permanent magnet cavity 40 between the heated die casing 30 and the outer diameter of the inner punch element 26. The dispensing mechanism 32 is the moved from its base position toward the longitudinal axis 24 of the punch and die mechanism 20, and thereafter fills the permanent magnet cavity 40 with encapsulated permanent magnet powder, as indicated in Figure 3.

After the permanent magnet powder filling operation, the dispensing mechanism 32 is returned to its original position and the dispensing mechanism 34 is moved toward the longitudinal axis 24 of the die mechanism 20. The inner punch element 26 is then retracted, as seen in Figure 4, to form a core cavity 42, which is immediately backfilled with encapsulated ferrous powder from the dispensing mechanism 34. The core cavity 42 is shorter than the permanent magnet cavity 40 due to differences in the apparent densities of the ferrous and permanent magnet powders.

After the ferrous powder filling operation, the dispensing mechanism 34 is returned to its base position, as seen in Figure 5, and the inner punch element 26 is further retracted to axially center the core cavity 42 within the permanent magnet cavity 40. At the same time, a pair of upper punch elements 44 and 46 are positioned in axial opposition to the inner and outer punch elements 26 and 28, as indicated, in preparation for compaction of the ferrous and permanent magnet powders.

As depicted in Figure 6, during the compaction step the oppositely disposed inner and outer punch elements 26, 44 and 28, 46 are concurrently forced toward each other, compressing each of the ferrous and permanent magnet powders to a desired height. As explained above, the ferrous and permanent magnet powders are initially filled to different levels to account for differences in the initial and final apparent powder densities.

The compaction, in combination with the heating of the die casing 30, causes the thermoplastic material coating the particles to fuse. This forms a rigid bond within and between the ferromagnetic core and permanent magnet regions 14 and 16. As shown in Figure 7, the upper punch elements 44 and 46 are retracted once the powders are compacted, and the inner and outer punch elements 26 and 28 are extended to their respective initial positions, as depicted in Figure 2, to eject the rotor assembly 10 out of the punch and die mechanism 20. In the illustrated embodiment, and as seen in Figure 7, the core rod 22 is fixed in the die mechanism 20, leaving a central opening 48 in the ferromagnetic core 14. In this case, manufacture of the rotor assembly 10 is completed with insertion of a shaft 12 through the opening 48, as mentioned above in reference to Figure 1.

With reference now to Figures 8 through 14, reference numeral 100 generally designates a motor frame and permanent magnet assembly 100 including an outer ferromagnetic frame 116 and one or more inner permanent magnets 114. The motor frame 116 is formed of a compacted ferrous powder, where the individual grains of the powder are encapsulated with a suitable thermoplastic material. As noted above, such thermoplastic materials

are well known in the art and will not be further discussed. Similar to the permanent magnet shell 14 of the permanent magnet rotor assembly 10 described above, the permanent magnets 114 are formed of a compacted magnetizable powder in which the individual grains of such powder are preferably encapsulated with a thermoplastic resin. In the course of manufacture, the thermoplastic materials fuse to form a unitary structure, the permanent magnets 114 being effectively bonded to the ferromagnetic frame 116. Alternatively, epoxy encapsulated magnetic particles may be used, and when so used are cured separately from the fusing of the thermoplastic encapsulant on the ferromagnetic particles. With a judicious choice of thermoplastic for the ferromagnetic powder and thermosetting resin for the magnetic particles, it may be possible to cure the thermoset and fuse the thermoplastic at the same time.

Following compression and fusing of the encapsulated powders, the motor frame and permanent magnet assembly 100 are placed in a magnetizing fixture (not shown) and subjected to a strong magnetic field to align magnetic regimes within the magnetizable powder, forming permanent magnet poles.

Similar to the permanent magnet rotor assembly 10 described previously, for purposes of the motor frame and permanent magnet assembly 100, the ferrous powder is predominantly iron while the permanent magnet powder is preferably the previously described "MAGNEQUENCH" composition marketed by General Motors Corporation. Similarly, the thermoplastic material encapsulating the ferrous and permanent magnet powders is preferably the amorphous polytherimide resin marketed by General Electric Corporation under the trademark "ULTEM". If a thermosetting resin is used to encapsulate the permanent magnet powders, a preferred epoxy resin is a suitable thermosetting resin with appropriate curing agent such as the materials disclosed in U.S. patent No. 4,558,077. The encapsulation process for the powders is identical to that described above in reference to the permanent magnet rotor assembly 10.

The manufacturing process of the motor frame and permanent magnet assembly 100 is illustrated in Figures 9 through 14, which depict a punch and die mechanism 120 during sequential manufacturing stages. The punch and die mechanism 120 is essentially identical to the punch and die mechanism 20 previously described for the manufacture of the permanent magnet rotor assembly 10, and includes a fixed central core rod 122 aligned along a longitudinal axis 124 of a heated die casing 130, inner and outer punch elements 126 and 128 slidably disposed between the core rod 122 and the heated die casing 130, and a pair of powder dispensing mechanisms 132 and 134 which are slidably disposed upon a die table 136 located at one end of the heated die casing 130. The upper end of the punch element 126 includes a plurality of circumferentially spaced fingers 139 defining therebetween mold cavities 140 for receiving and shaping the magnets. Further discussion of the punch and die mechanism 120 will be omitted here because of the previous relevant discussion pertaining to the permanent magnet rotor assembly 10.

As shown in Figure 9, the inner and outer punch elements 126 and 128 are initially extended to expel any foreign matter from the die casing 130. The inner punch element 126 is then retracted, as shown in Figure 10, to form an annular array of permanent magnet cavities 140 between the inner diameter of the outer punch element 128 and the outer diameter of the central core rod 122. The dispensing mechanism 132 is then moved from its base position toward the longitudinal axis 124 of the punch and die mechanism 120, and thereafter fills the permanent magnet cavities 140 with encapsulated permanent magnet powder, as indicated in Figure 10.

After the permanent magnet powder filling operation, the dispensing mechanism 132 is returned to its original position and the dispensing mechanism 134 is moved toward the longitudinal axis 124 of the die mechanism 120. The outer punch element 128 is then retracted, as seen in Figure 11, to form a frame cavity 142 which is immediately backfilled with encapsulated ferrous powder from the dispensing mechanism 134. The lengths of the permanent magnet cavities 140 and frame cavity 142 are predetermined to compensate for differences in the apparent densities of the ferrous and permanent magnet powders.

After the ferrous powder filling operation, the dispensing mechanism 134 is returned to its base position, as seen in Figure 12, and the inner punch element 126 is further retracted to axially center the annular array of permanent magnet cavities 140 within the frame cavity 142. At the same time, a pair of upper counterpunch elements 144 and 146 having end shapes complimentary to their opposed punches 136 and 128 respectively are positioned in axial opposition to the inner and outer punch elements 126 and 128, as indicated, in preparation for compaction of the ferrous and permanent magnet powders.

As depicted in Figure 13, during the compaction step the oppositely disposed inner and outer punch elements 126, 144 and 128, 146 are concurrently forced toward each other, compressing each of the ferrous and permanent magnet powders to the predetermined desired heights as explained above. The compaction, in combination with the

heating of the die casing 130, causes the thermoplastic materials, which coat the powder particles, to fuse, forming a rigid bond within and between the permanent magnet regions and ferromagnetic frame 114 and 116, respectively.

As shown in Figure 14, the upper counterpunch elements 144 and 146 are retracted once the powders are compacted, and the inner and outer punch elements 126 and 128 are extended to their respective initial positions, as shown in Figure 9, to eject the motor frame and permanent magnet assembly 100 out of the punch and die mechanism 120. In the illustrated embodiment, and as seen in Figure 14, the core rod 122 is fixed in the die mechanism 120, leaving a central opening 148 in the frame 114.

As will be apparent, dynamoelectric devices having both ferromagnetic and permanent magnet regions can be readily manufactured, even under high volume production conditions, such as found in the auto industry. Moreover, the permanent magnets are formed as integral regions of the dynamoelectric device so as to form a unitary dynamoelectric device.

The method also allows for the location and size of the permanent magnet and ferromagnetic regions to be varied relative to the dynamoelectric device, facilitating alterations to the design of the dynamoelectric device without undue processing modifications.

Therefore, while a preferred embodiment has been described, it is apparent that other forms could be adopted by one skilled in the art, such as using alternative thermoplastic materials, or thermoset materials to encapsulate one or both powders. Moreover, alternative permanent magnet and ferromagnetic materials may be employed.

The disclosures in United States patent application no. 837,124, from which this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

Claims

1. A method of manufacturing a component of a magnetic device which includes regions of dissimilar magnetic properties formed from encapsulated powders, comprising the steps of forming a first cavity (40,142) which includes a predetermined inner periphery and an outer periphery substantially corresponding to an outer periphery of the magnetic device; filling the first cavity with a first powder having predetermined magnetic properties, individual particles of the first powder being encapsulated with a first bonding agent; forming a second cavity (42,140) within the first cavity, the second cavity including an outer periphery delimited by the inner periphery of the first cavity; filling the second cavity with a second powder having magnetic properties different to the magnetic properties of the first powder, individual particles of the second powder being encapsulated with a second bonding agent; and heating and compacting the first and second powders to fuse and compact the first and second powders, so as to form a unitary structure including a core (14,114) surrounded by a shell (16,116), the core and shell having dissimilar magnetic properties.

2. A method according to claim 1, including the step of inserting a shaft (22,122) within the second cavity to form an axial opening in the core.

3. A method according to claim 2, wherein the step of heating and compacting includes the step of securing the shaft to the secong powder so as to provide a shaft for the device.

4. A method according to any one of claims 1 to 3, wherein the first and second powders have different compressibilities; the step of compacting the powders including the steps of displacing the first powder substantially to centre the second cavity within the first cavity; and individually and concurrently compacting the first and second powders from opposing ends of the first and second cavities.

5. A method according to any preceding claim, wherein the first or second bonding agent is an epoxy resin.

6. A method according to any preceding claim, wherein the first or second bonding agent is a thermoplastic material.

7. A method according to any one of claims 1 to 4, wherein the first and second bonding agents are thermoplastic materials.

8. A method according to claim 7, wherein the first and second bonding agents are of the same thermoplastic material.

9. A method according to any preceding claim, comprising the steps of retracting a punch element (126) used in delimiting the inner periphery of the first cavity so as to form an array of second cavities; filling each of the second cavities with the second powder; and forming a unitary structure which includes a core including an array of core elements (114) disposed

within a shell.

10. A method according to any preceding claim, wherein the first and/or second cavities are generally substantially annular.

11. A method according to any preceding claim, wherein the method is adapted to manufacture a permanent magnet rotor, the core being formed by filling the second cavity or cavities with a ferrous powder.

12. A method according to any one of claims 1 to 10, wherein the method is adapted to manufacture a motor frame and permanent magnet assembly, the shell being formed by filling the first cavity with a ferrous powder.

Fig.1.

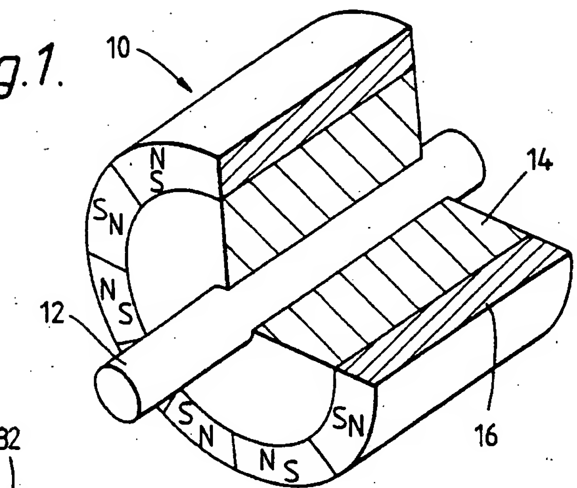

Fig.2.

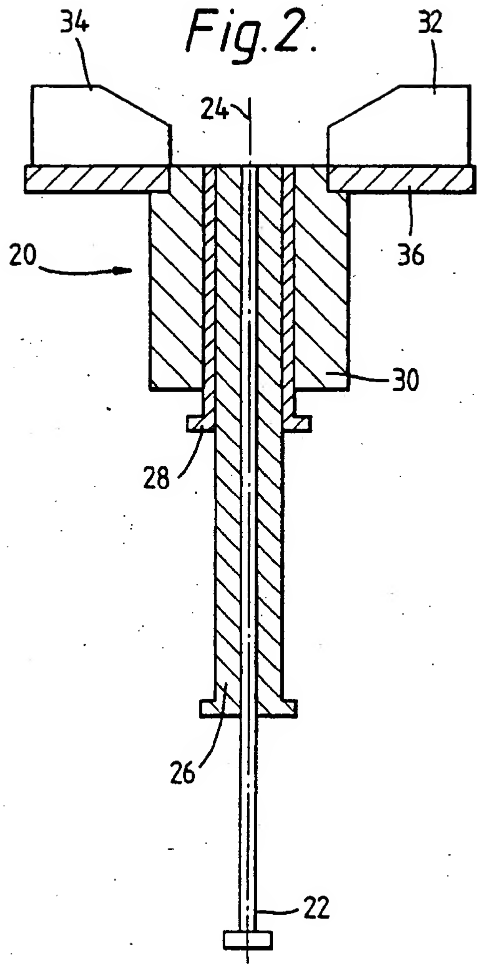

Fig.3.

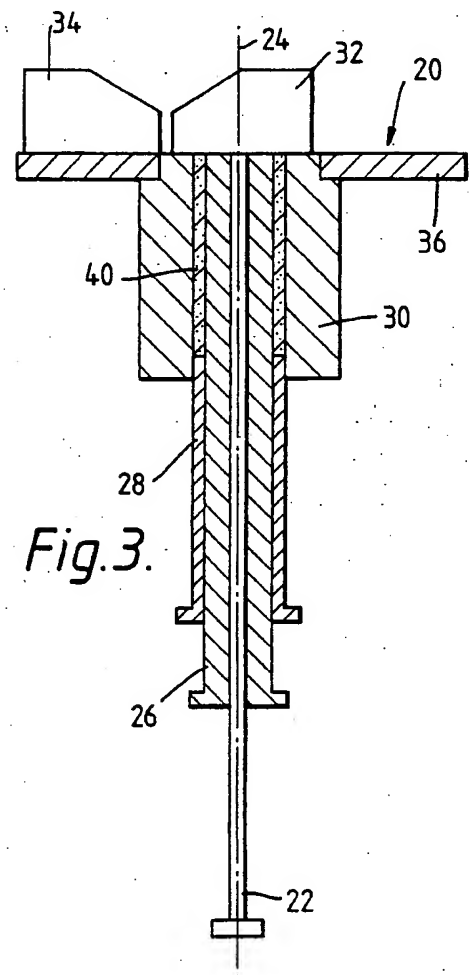

Fig. 4.

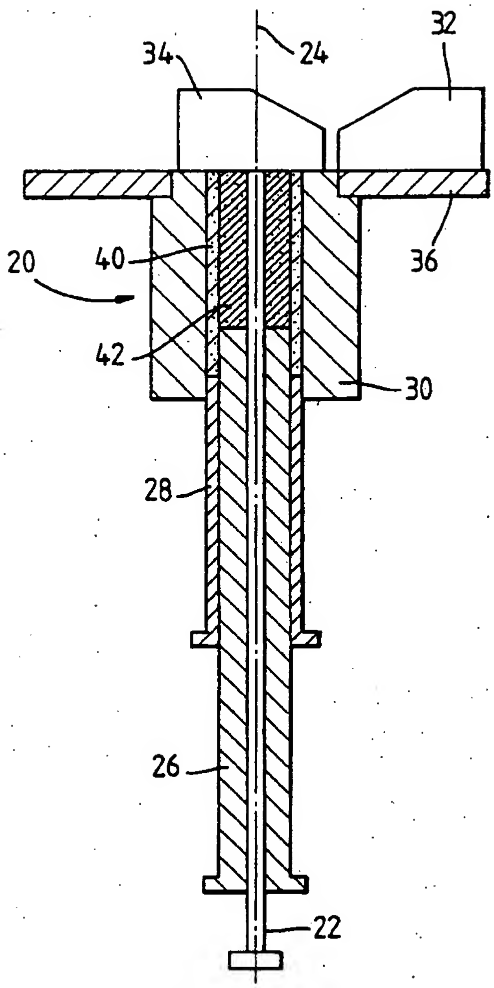

Fig. 5.

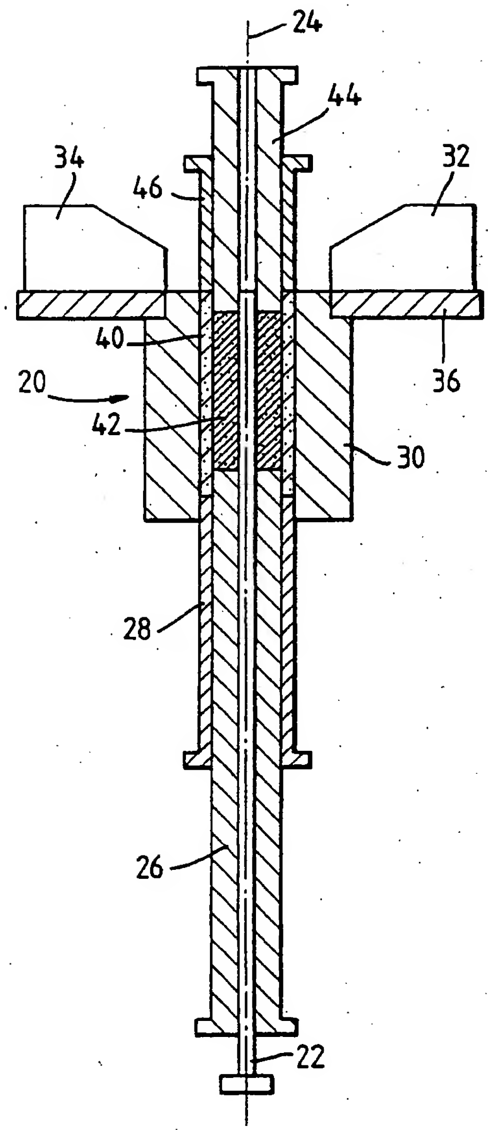

Fig.6.

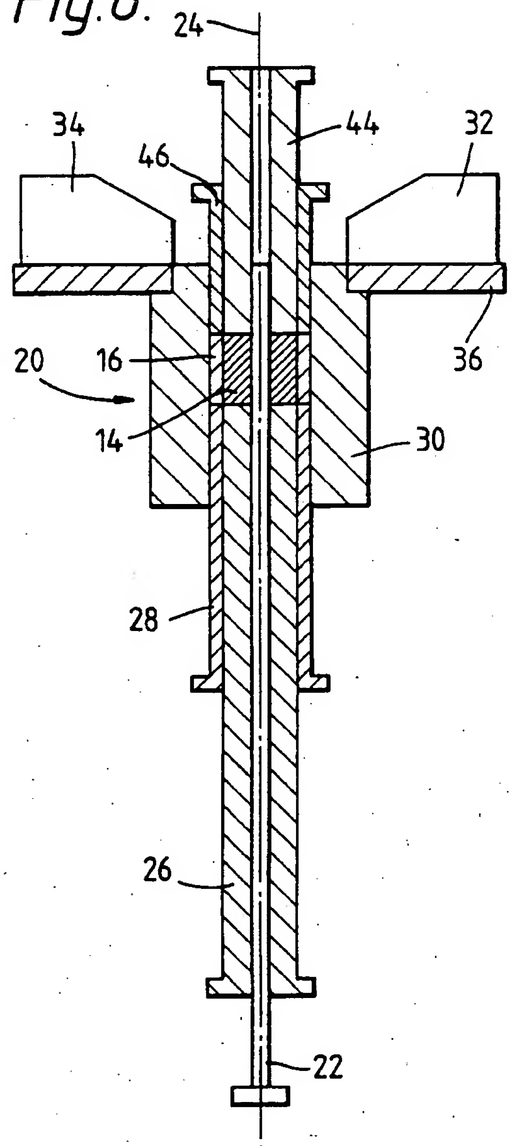
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Fig.7.

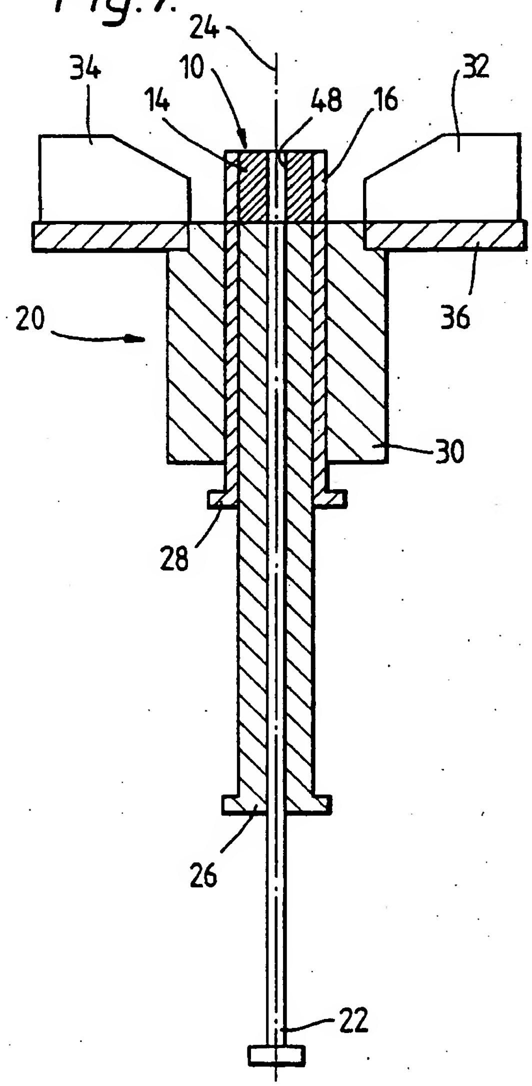
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Fig.8.

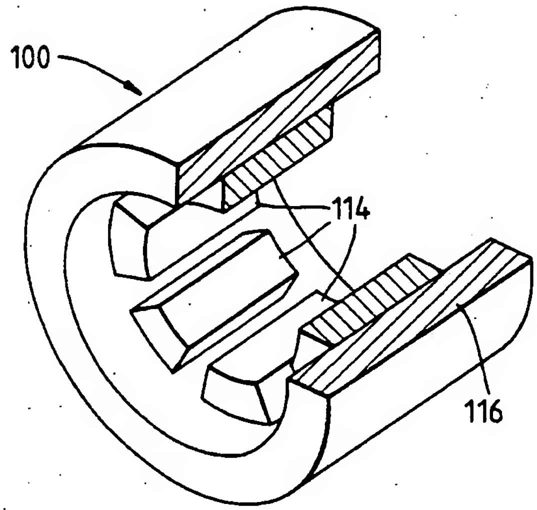
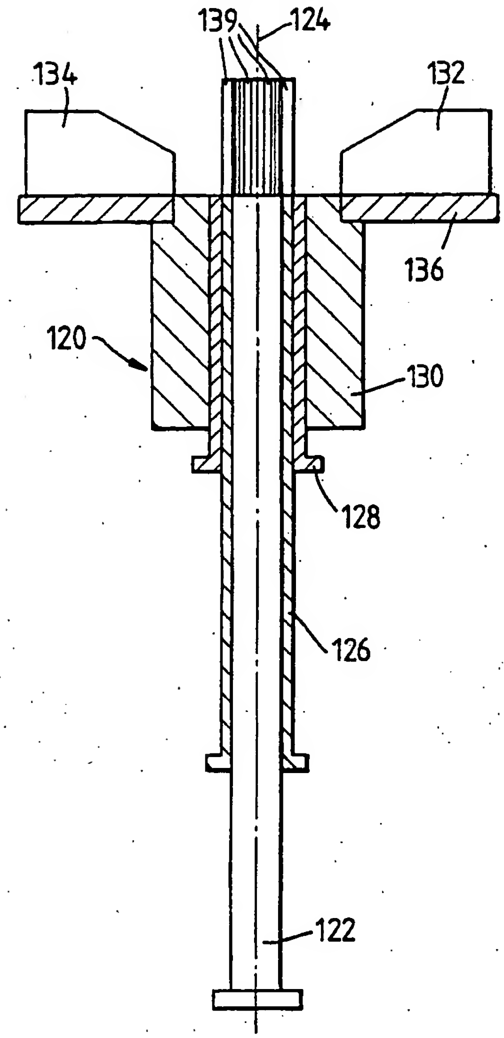


Fig. 9.



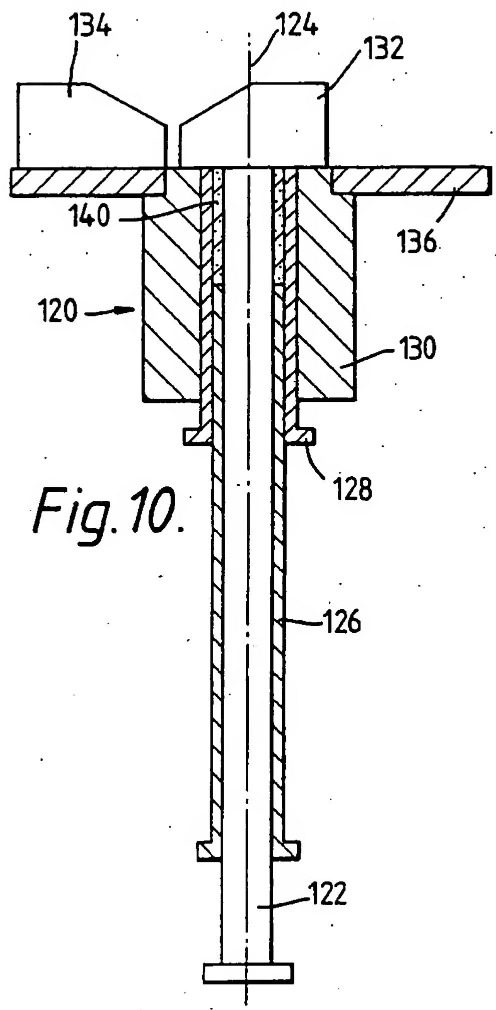


Fig.10.

Fig.11.

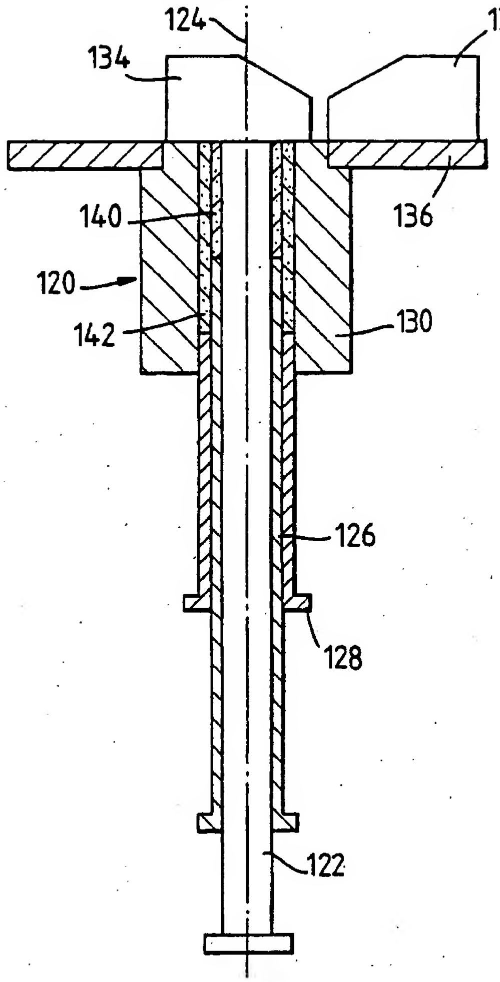

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Fig.12.

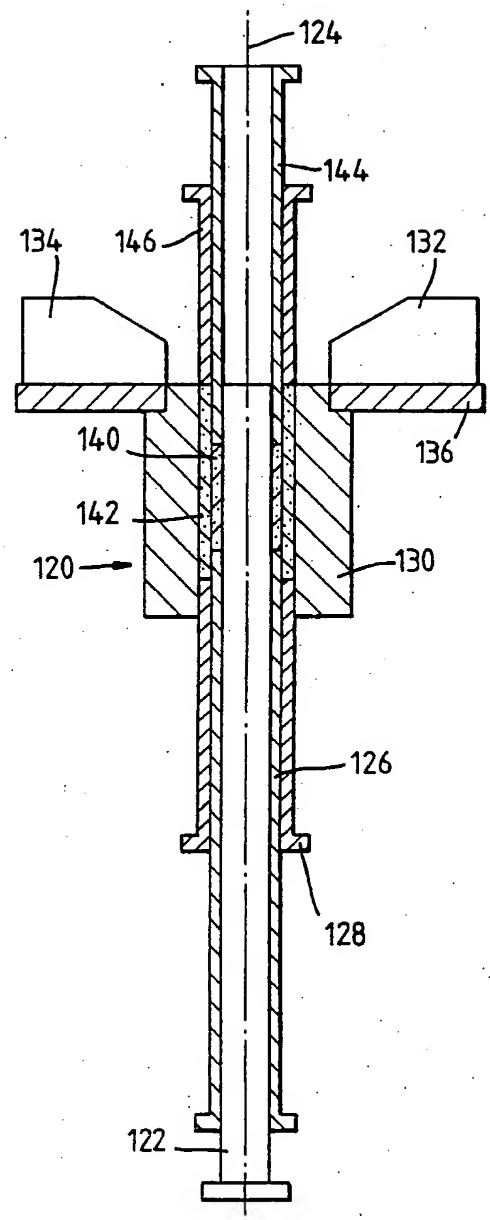
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Fig.13.

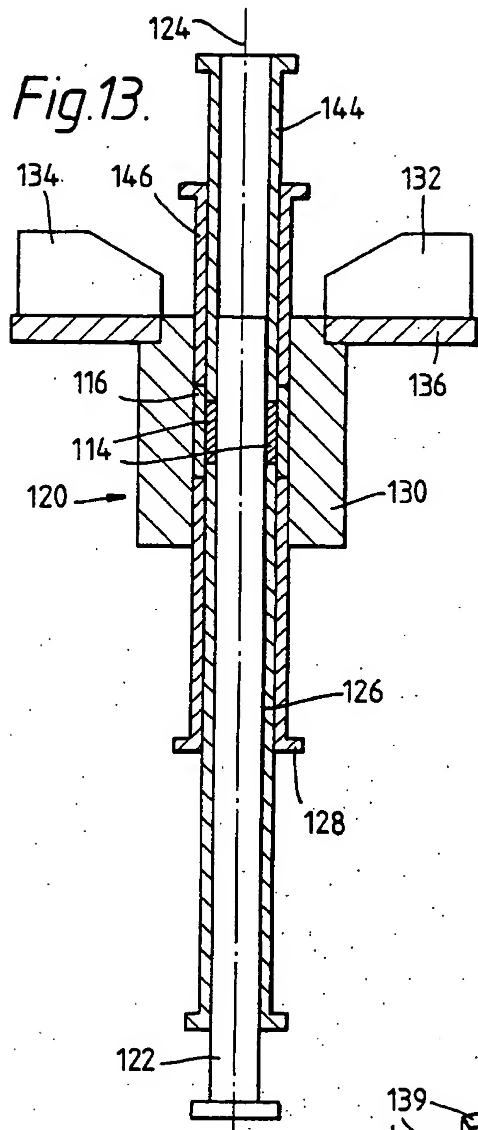

Fig.14.

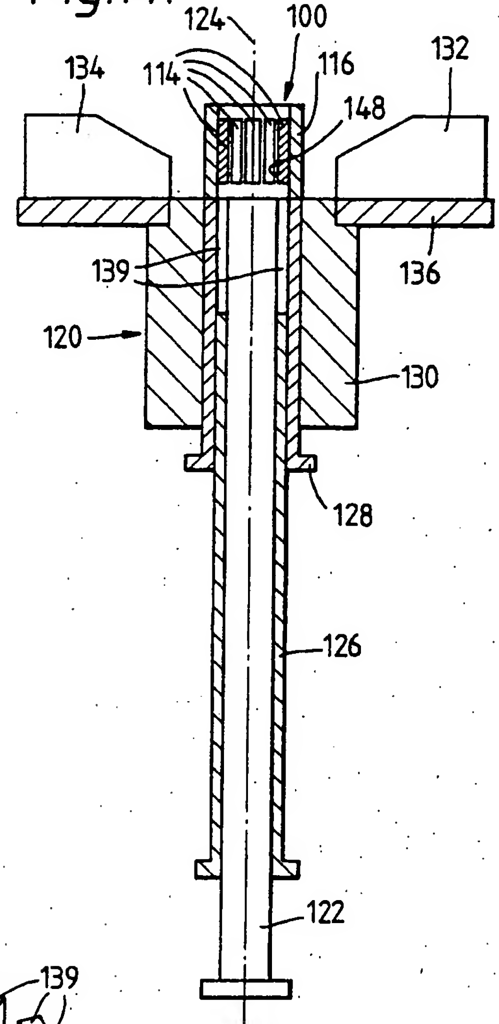

Fig.15.